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the meteorological magazine

OCTOBER 1967 No 1143 Vol 96

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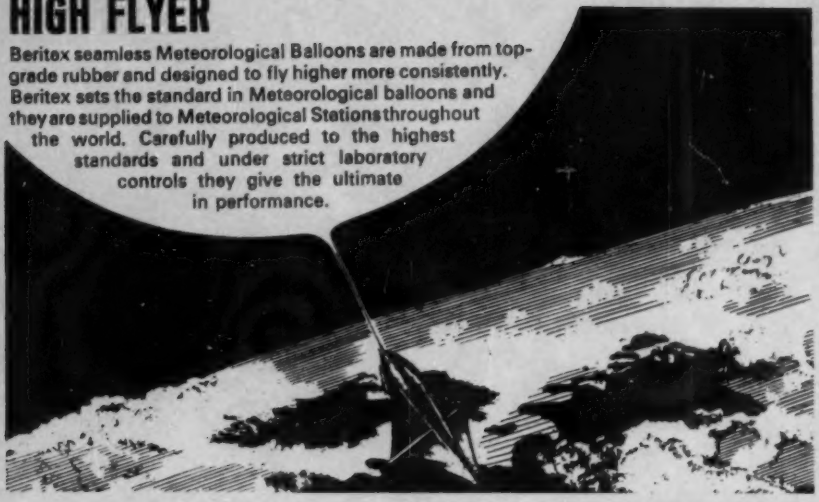

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By P. J. L. WILDMAN

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(ii) The measurement of radio noise from our own galaxy between 2 Mc/s and 5 Mc/s. These frequencies are normally absorbed by the ionosphere and so cannot be measured from the earth (Jodrell Bank, Manchester University).

(iii) The measurement of radio noise from terrestrial sources, such as lightning discharges, and its geographical distribution through the day and with the seasons (Radio and Space Research Station (RSRS), Science Research Council).

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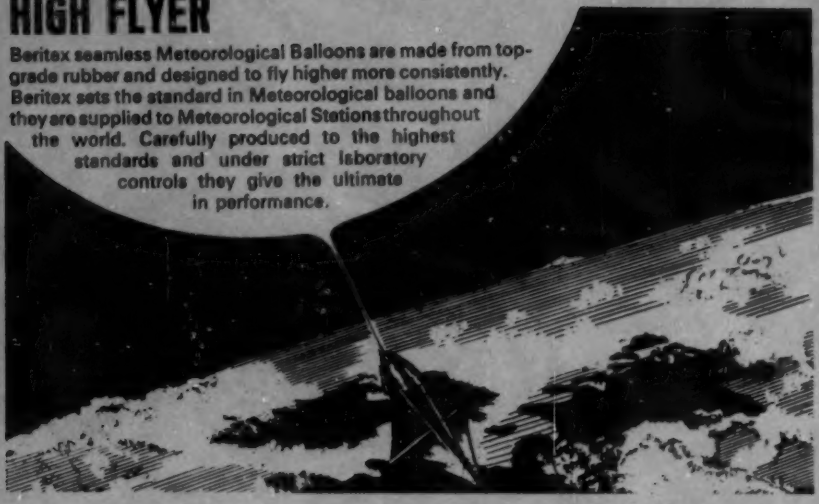

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(iv) The measurement of the intensity of very low frequency (VLF) radiation at various regions in the ionosphere, and the variation of this intensity in space and time (Sheffield University).

(v) The measurement of the vertical distribution of molecular oxygen (O_2) at heights above the earth where it is being dissociated by solar ultra-violet (u.v.) radiation, and of changes in this distribution in space and time (Meteorological Office).

The first four experiments give a comprehensive picture of the state of the ionosphere especially as regards radio propagation. The Meteorological Office experiment was included because of interest in the composition and heating processes of the atmosphere at heights where dissociation of O_2 is taking place. Previously, few such molecular oxygen distribution measurements had been made from sounding rockets[1,2] and a satellite enables many more measurements to be made, well distributed over the earth and extending over a long period. In addition, all these measurements are made with the one piece of equipment.

When these five experiments had been chosen the choice of orbit remained and the greatest conflict here was between the experiment measuring galactic radio noise (Jodrell Bank), and that measuring terrestrial radio noise (RSRS). Normally galactic radio noise is absorbed by the ionosphere below about 500 km so that it cannot be received by a satellite orbiting below this height. Similarly, because of absorption by the ionosphere little terrestrial radio noise reaches above about 550 km and thus a compromise height of orbit was needed so that both experiments could receive a useful amount of signals through the lifetime of the satellite. In addition, the Birmingham University electron experiment was best suited to constant height (circular orbit), and the Meteorological Office required only a minimum height, so that the satellite was above any expected molecular oxygen. This minimum height is about 350 km and the accuracy of measurement of O_2 is reduced at any height above this. The orbit chosen finally was a circular one of 550 km above the earth at an inclination of 80 degrees to the equatorial plane of the earth. This inclination ensures that the satellite passes over the auroral regions and also that the plane of the orbit precesses in space by several degrees per day to give the Meteorological Office experiment good coverage over the earth within a few weeks of launch.

Information from the five experiments may be received in 'real time' whenever the satellite is within range of one of the sixteen ground receiving stations. It may also be stored on a tape recorder within the satellite and played out on command from the ground as the satellite passes within range of a ground receiving station. The Meteorological Office experiment uses only the 'real time' system since this allows data to be transmitted at the high rate required by the experiment. The satellite is within range of a ground receiving station for between one quarter and one third of its orbit so that a great deal of information may be obtained using only the 'real time' system. (There are approximately fifteen orbits round the earth per day, each one with a satellite 'sunrise' and satellite 'sunset', when densities of O_2 may be obtained.)

The spacecraft.—The main structure of the satellite was built by the British Aircraft Corporation (BAC) Guided Weapons Division at Stevenage, the power supply and telemetry equipment by the General Electric Company at Portsmouth, and the Royal Aircraft Establishment (RAE), Farnborough, was the overall design authority on behalf of the Ministry of Technology

(formerly Ministry of Aviation). The equipment for the scientific experiments was provided by the experimenters themselves; some groups had this built by outside contractors, and some, such as the Meteorological Office, constructed it within their own establishments.

The basic layout of the satellite in its orbital configuration is shown in Figure 1.[3] The four booms are locked in their erected position and the

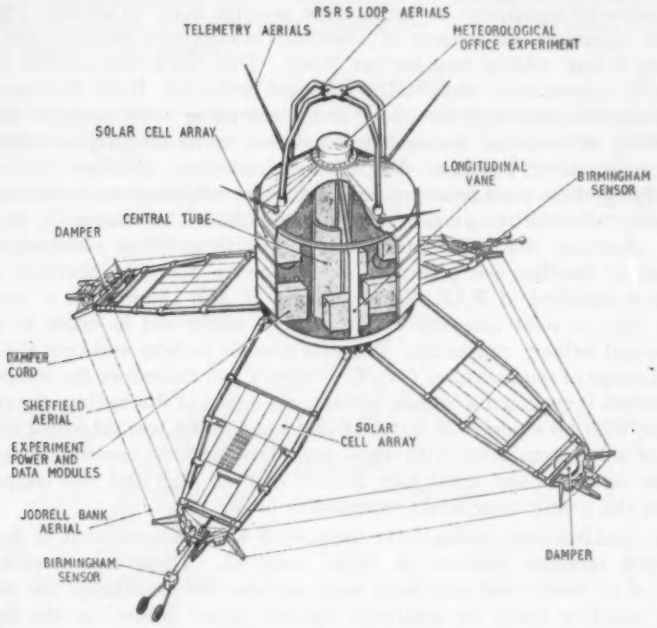

FIGURE 1—ARIEL 3 SATELLITE IN SECTION

From Campbell,[3] by courtesy of the Royal Meteorological Society

cut-away section indicates the internal construction. Four equally-spaced longitudinal honeycomb vanes are fixed to the stiff centre tube, which provides the main rigidity of the structure. Most of the electronics of the satellite itself, and of the experiments, are fixed to these vanes. The solar cells which power all the satellite systems and experiments and which also recharge the battery for operation in the earth's shadow, are mounted on the booms and on the parallel surfaces of the main body. The Meteorological Office experiment is mounted on the conical top of the satellite to allow 360 degree field of view around the central spin axis of the satellite and a view 45 degrees above and below the equatorial plane of the satellite. The antennae of the Sheffield University and Jodrell Bank experiments are wound from tip to tip of the four booms, and the sensors of the Birmingham University experiment are mounted on the ends of two of these booms. The RSRS antenna is mounted on the top cone and causes no interference with the Meteorological Office experiment field of view.

Once the overall shape and structure of the satellite had been decided it was essential to prove that the structure, including all its mechanical and electronic components, was able to withstand the vibrations and accelerations of launch as well as all the conditions existing during orbit. For this purpose five satellites were built, the first one being used for mechanical integration trials, and the second for electrical compatibility trials. The compatibility work on the second satellite lasted several months and consisted of adding each piece of equipment in turn to the satellite main structure. The object was to eliminate all sources of electrical interference between the various systems before adding any further items. This work was carried out in a specially constructed electrically screened room at BAC Stevenage, any interference found being eliminated or minimized by extra electrical screening, rerouteing of electrical wiring between items, or by filtering introduced into the circuitry when possible. The third or 'prototype' satellite was completed embodying these modifications, and was then subjected to acceleration and vibration of severity 50 per cent greater than that expected at launch. After checking that all systems were still functioning satisfactorily, this 'prototype' satellite was placed in the 2·5-metre diameter 'thermal vacuum' chamber installed at RAE, Farnborough. In this chamber it is possible to apply light of solar intensity to the satellite under test in order to evaluate its thermal balance properties. It is also possible to heat and cool the satellite over a range of temperatures (−15°C to +60°C) to reproduce the temperatures the satellite is expected to attain in orbit. As a part of this testing, the complete satellite with all equipment installed and functioning was subjected to several days of solar simulation with light and dark periods corresponding to the satellite orbit. It also spent long periods at both high and low temperatures beyond the temperature limits expected in orbit.

The modifications arising from these trials were incorporated in the fourth and fifth satellites (known as 'flight' models). These two satellites were identical in every way and both were suitable for launching, the duplicate 'flight' satellite being an insurance against rocket failure, or the failure of the satellite in its early life in orbit. The 'flight' models were given low-level vibration and thermal vacuum tests, and individual experimenters were responsible for subjecting their flight experimental packages to low-level thermal vacuum and vibration testing before assembly of the satellites. The vibration testing of the Meteorological Office package was carried out at Atomic Weapons Research Establishment (AWRE), Aldermaston, whilst a small thermal vacuum facility was set up at Bracknell.

The Meteorological Office experiment.—At heights about 100 km above the earth, molecular oxygen (O_2) is dissociated by short-wave u.v. light from the sun. This effect increases with height so that at about 200 km the dissociation is almost complete, although some molecular oxygen is found at high levels. Little is known of the actual density of molecular oxygen at these heights or how it varies geographically and with time. Knowledge about this dissociation process is essential to our understanding of the physics of the atmosphere at these heights and of the possible effects of the dissociation process on the atmosphere at lower levels. In addition, the dissociation process at lower levels leads to the formation of ozone whose absorption of u.v. light of longer wavelengths is an important factor in the heat budget of the atmosphere down to as low as 20 km.

The principle used in the experiment is to observe the attenuation of u.v. light for a wavelength which is absorbed only by molecular oxygen. As the satellite enters or leaves the shadow of the earth it may be seen from Figure 2 that the 'grazing ray' from the sun to the satellite passes through the atmosphere. As the satellite moves, the ray passes through different height regions in the atmosphere and the intensity of u.v. light reaching the satellite depends on how much has been absorbed by molecular oxygen in the path. If $(I_{max}^{i})_\lambda$ is the intensity of light of wavelength λ reaching the detector when no attenuation occurs, then when the 'grazing ray' is at height h the intensity will have fallen to $(I_h)_\lambda$ where :

$$(I_h)_\lambda = (I_{max})_\lambda \exp\ (-\sigma_\lambda N_h)$$

and σ_λ is the absorption cross section of O_2 at wavelength λ and N_h is the total number of O_2 molecules between the sun and the detector when the 'grazing ray' is at height h. By taking successive readings of the intensity of the chosen wavelength the density of molecular oxygen at various heights can be calculated. The path of the satellite varies with time and therefore observations can be made at different latitudes around the earth.

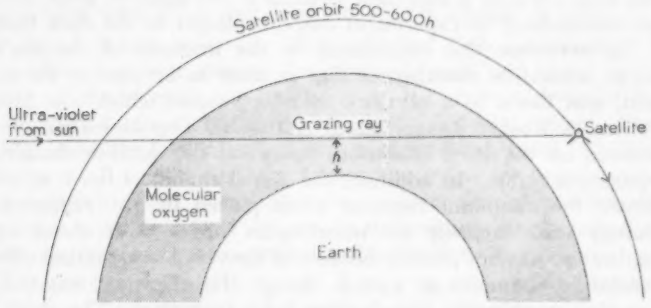

FIGURE 2—DIAGRAM SHOWING SATELLITE ENTERING THE EARTH'S SHADOW WITH THE 'GRAZING RAY' SCANNING THROUGH THE EARTH'S ATMOSPHERE

On the diagram, 500–600h indicates the height of the satellite's orbit in kilometres.

The maximum absorption cross-section of molecular oxygen occurs at 1450 Å and has a value of $1{\cdot}48 \times 10^{-17}$ cm^2.[4] If we observe the attenuation at 1450 Å we will be able to detect the smallest possible quantity of O_2. It is essential to use a detector which has a narrow band response to u.v. light so that ideally we can consider monochromatic light, and the detectors used in this experiment are ionization chambers. In these, the lower wavelength of the pass-band is set at 1425 Å by artificial-sapphire windows, and the upper limit is set at 1490 Å by the ionization wavelength of the Para-Xylene ($C_6H_4(NH_2)_2$) gas filling. Light between these two wavelengths causes ionization of the Para-Xylene within the chamber, and the charge thus produced gives a measure of the light intensity.

Four of these chambers are mounted 90 degrees apart in the Meteorological Office apparatus and each of them points in turn at the sun as the satellite rotates at 30 rev/min about the central spin axis. The four chambers are

connected as a single d.c. amplifier and it is the output of this which is telemetered directly to the ground stations. Baffles are placed over three of the ionization chambers thus eliminating reflections from the satellite body and restricting the field of view of each to a cone (of 45 degrees half-angle) so that only one chamber sees the sun at a time. These baffles also contain a gauze to allow for the variations between individual ionization chambers and also to reduce the overall u.v. flux. The field of view of the fourth chamber was specially restricted as described later.

Practical difficulties arose concerning the sensitivity of these ionization chambers to wavelengths outside the theoretical pass-band, and particularly in the wavelength region around 2000 Å. Here the sun is much more intense than in the 1450 Å region and in addition is not attenuated by molecular oxygen, so that it can produce a large, unwanted, steady signal which takes up valuable telemetry range. This signal could be ignored or 'backed off' within the circuitry of the instrument if its magnitude could be forecast accurately before launch. However, the absolute intensity of the sun's u.v. radiation is not known with sufficient accuracy to avoid waste in the use of the satellite's telemetry system. In this system the output range of the experiment from 0 to +5 volts is expressed in terms of 100 discrete 'filter' numbers, which are reconverted to experiment output voltages in the data reduction process. To overcome this uncertainty in the intensity of the sun's u.v. radiation, an ionization chamber, similar to those to be used in the satellite experiment, was flown in a SKYLARK sounding rocket which was launched at the Woomera Rocket Range, South Australia. This ionization chamber was calibrated on the same laboratory system as the satellite chambers, to reduce systematic errors. In addition, the actual chambers flown in ARIEL 3 were selected for minimum response when placed in u.v. radiation with approximately solar intensity for wavelengths longer than about 1900 Å. Actual calibration was not possible because of the very low quantum efficiency of the ionization chambers at 1900 Å though the efficiency was still high enough to give troublesome signals from solar intensities. The most likely cause of this sensitivity was thought to be photo-emission from the conducting walls of the chambers.

Launched early in March 1967, the rocket reached a height of 206 km, and showed that at this height the sun's u.v. radiation in the 1425 Å to 1490 Å band was much less than the published figures indicated. The launch took place at about 1500 hours local time so that the ionization chamber viewed the sun almost vertically through any O_2 that remained above it, and it was estimated that the signal attained at apogee was within 1 per cent of the true 'full sun signal'. This result of low solar intensity led to gauzes of higher transmission being placed over three of the four ionization chambers in the experiment thereby making use of the full range of the satellite telemetry system. In front of the fourth ionization chamber there was placed a narrow slit which greatly restricted the field of view of the chamber. This was to prolong the lifetime of the chamber, since it had been found in the laboratory that prolonged exposure of this type of chamber to u.v. radiation of solar intensity at wavelengths longer than approximately 1900 Å, caused a permanent loss of sensitivity probably by destruction of the gas filling. The slit reduced the u.v. flux to one-third of the full value so that the estimated life of the detector was about three months, and data of reduced accuracy should

be obtained for this period. It was estimated that the useful life of the other three ionization chambers with their larger field of view would be about one month in orbit.

The launch.—The satellite was successfully launched at the first attempt by a NASA four-stage SCOUT rocket, on 5 May 1967, from Vandenberg Air Force Base, between Los Angeles and San Francisco, California (Plates I, II and III). An elliptical orbit between 500 km and 600 km was attained, and the booms and equipment mounted on them all deployed correctly. The time of launch, 1630 GMT, was chosen to allow the Meteorological Office to obtain data for a number of days before the plane of the satellite orbit precessed to a position perpendicular to the earth–sun line. In this 'all sun' condition the Meteorological Office experiment obtains no useful results since the satellite never enters the earth's shadow, and in addition the rate of decay of ionization chamber sensitivity slightly increases. With this orbit, at 80 degrees inclination, 'all sun' periods occur about every 55 days and last about 18 days. The launch at 1630 GMT allowed seven days of Meteorological Office results before the 'all sun' condition and also meant that the RSRS terrestrial radio noise experiment passes over equatorial regions at afternoon local time, when thunderstorm activity reaches its peak.

The initial signals from the Meteorological Office experiment indicate 'full sun signals' at very close to the expected levels, and in the first month's operation of the satellite the sensitivity of the three wide-angle ionization chambers has fallen to about one-third of its initial value. The fourth ionization chamber has lost its sensitivity more slowly, and it is hoped that useful results will be obtained from it after the end of the first 'all sun' period. During the first seven days operation, oxygen density profiles should be derived over a wide range of latitudes in the southern hemisphere for satellite 'sunsets', and in the northern hemisphere for satellite 'sunrises'.

Data are being received from 12 tracking stations of the NASA Satellite Tracking and Date Acquisition Network (STADAN) which has stations throughout the world, and also by the 3 stations run by the Radio and Space Research Station, one at Winkfield near Bracknell, one at Singapore, and one in the Falkland Islands. An additional station, operated on a non-routine basis by Stanford University, is at Byrd Station in the Antarctic. This station received many satellite 'sunsets' in the first few days after launch but these results will not be received until the supply ship returns from Antarctica sometime late in 1967.

The data tapes from all these 16 stations eventually reach the Radio and Space Research Station for preliminary sorting and processing. After this, the data are passed to AWRE, Aldermaston, to make separate data-tapes for each experiment in a form suited to the processing requirements of the experimenters concerned. The Meteorological Office will carry out the final analysis of the data for their experiment on the computer at Bracknell.

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THE CONFERENCE OF COMMONWEALTH METEOROLOGISTS 1967

By H. M. RACE

It is customary for the four-yearly Congress of the World Meteorological Organization (WMO) to be followed by a Conference of Commonwealth Meteorologists in the United Kingdom, as was the pattern this year when the 8th Conference was held at the Meteorological Office Headquarters at Bracknell from 9 to 12 May. The Conference is essentially one of informal discussions in which Commonwealth members exchange views, and most of those who attend are Directors of Meteorological Services in Commonwealth countries. This year there were representatives from Nigeria, Botswana, Hong Kong, Mauritius, Ceylon, Zambia, New Zealand, Australia, India, the Caribbean, Canada, Singapore, Barbados and the East African Common Services Organization. The Director of the Meteorological Service of Ireland attended as an observer. (See Plate IV.)

The Conference was opened by Mr Merlyn Rees M.P., Parliamentary Under-Secretary of State for Defence (Royal Air Force), who also received the guests at a Government reception held at Lancaster House on the evening of the first day. The Commonwealth members of the Conference were the Guests of Honour at the reception, and other guests included the associated Commonwealth High Commissioners, staff of the Meteorological Office, and representatives from the Ministry of Overseas Development, the Commonwealth Office, the Board of Trade and the Ministry of Defence.

Mr Merlyn Rees, congratulated delegates on the part they had played at the recent WMO 5th Congress in Geneva, and in particular congratulated those who had been appointed to the Executive Committee. Mr W. J. Gibbs, Australia, and Mr N. A. Akingbehin, Nigeria, had been elected Vice-Presidents of the Executive Committee and 7 of the 24 members of that Committee were from the Commonwealth, as were 7 of the 8 Presidents of Technical Commissions. Mr Rees extended a special welcome to the representatives of those countries which had achieved independence within the Commonwealth since the previous Conference in 1963. After referring to the rapid pace of technological development as it affected meteorology today through the use of computers, satellites, rockets, radar and modern methods of communication, Mr Rees said that in Geneva the nations of the world had endorsed the World Weather Watch (WWW) plan, which was perhaps the largest and most imaginative scheme of international co-operation ever undertaken in the scientific field. Commonwealth countries would have a vital role to play in the development of WWW and in the great co-operative effort which it would demand. Mr Rees wished the Conference well and expressed the hope that it would further promote the spirit of co-operation and friendship which existed between the Meteorological Services of the Commonwealth.

The Director-General, Dr Mason, then welcomed the delegates and expressed particular pleasure in having been able to work with many of them at the Geneva Congress. He outlined the future plans of the Meteorological Office and its problems, saying that the use of the computer for the production of forecast charts was a major step forward but it also necessitated major changes in staffing, organization and training for the future.

After making reference to the growing demand for meteorological services, to the results in long-range forecasting and to the work of the branch recently established for hydrometeorology, the Director-General said that on the research side the Meteorological Office was expanding its effort and hoped to double the number of research scientists over the next 5 to 7 years. Generally, the policy was not to spread the effort thinly over the whole research field but to concentrate on a number of main issues such as large-scale and meso-scale dynamics, the high atmosphere, turbulence, cloud physics, geophysical fluid dynamics and tropical meteorology.

The Director-General went on to say that he was greatly encouraged by the rapidly improving status of meteorology within the United Kingdom scientific community, and by the sympathy and support he had received from the Government. He looked forward to the Meteorological Office playing its full part in WWW and the other exciting developments that lay ahead. He hoped that the Office, in close collaboration with industry and with other large government laboratories, would speed the development of new instruments and techniques on which progress in meteorology would largely depend, and that a good deal of the satellite technology required for the late phases of WWW would be developed in Europe.

In closing, the Director-General said how much he and his colleagues were looking forward to a vigorous exchange of views with the delegates and that he would like them to regard it as an opportunity to discuss their problems and not hesitate to suggest changes in the agenda to meet their needs and wishes.

The Director-General then took the Chair in the ensuing discussion which mainly concerned the place of research in relation to meteorological services and the particular question of an increased effort in the field of tropical meteorology. Certain aspects of a Nigerian paper on Joint Research Projects within the Commonwealth were discussed at this meeting and again, later in the week, at the research and training discussion.

The afternoon subject was Numerical Forecasting, the opening speakers being Mr R. F. Zobel, Assistant Director (Central Forecasting), and Mr F. H. Bushby, Assistant Director (Forecasting Research).

On the second day Dr R. Frith, Assistant Director (High Atmosphere), and Mr T. H. Kirk of the Central Forecasting Office opened the discussions on Rocket and Satellite Meteorology, and Mr R. H. Clements, Deputy Director (Observational Services), opened the discussion on Hydrometeorology. During the afternoon members visited a number of Headquarters branches including the Central Forecasting Office, Telecommunications, Data Processing, and the laboratories of the branches dealing with the high atmosphere and with instruments. Dr N. E. Rider of the Instruments and Observations Branch demonstrated the British Automatic Weather Station by a round-the-world

call to Australia. This was a successful experiment and afterwards a representative of the branch said that the transmission distortion was in fact smaller than that experienced during many local calls.

The Research and Training discussion on the morning of the third day was led by the Director of Research, papers being presented on Long-range Weather Forecasting by Mr R. A. S. Ratcliffe, Assistant Director (Synoptic Climatology,) and on Meteorological Training by Mr C. J. Boyden, Assistant Director (Publications and Training). At this meeting delegates to Conference expressed particular thanks for the work of the Meteorological Office Training School.

'Problems arising in the implementation of World Weather Watch' was the afternoon subject, and the discussion was opened by Mr W. J. Gibbs, Director of the Bureau of Meteorology, Australia.

Mr Gibbs gave a brief exposition of the main features of WWW and its five aspects : Global Observing System, Global Data-Processing System, Global Telecommunications System, Research and Training. He said that the implementation plan adopted by the WMO 5th Congress was complex, with national and bi-lateral elements and a Voluntary Assistance Programme. He grouped the benefits under several headings.

Public relations.—A worth-while achievement would be the resulting increased awareness, by public administrations and politicians, of the benefits obtainable from meteorological services.

The benefit to the science.—The study of the atmosphere would be promoted through additional observations, new techniques and the knowledge thus obtained.

Operational work.—This would be improved by better and more rapid transmission of information, especially in the southern hemisphere where satellites were already of great benefit.

Weather control.—There was, however, no suggestion of a comprehensive programme and the subject had been played down at Congress.

Prediction.—The Global Atmosphere Research Programme would be of great importance in relation to the question of whether there is a practical limit to the predictability period.

Mr Gibbs went on to emphasize that WWW must benefit all the Members and should try to close the gap between the more developed and the less developed services, which otherwise could well widen. The northern hemisphere areas would certainly see progress and the tropics ought to benefit, but one could not be confident of the relative amounts of benefit.

In the general discussion which followed there were references to the quality of staff and observations and the effect of WWW on these. One view was that once the number of ship observations increased under a forced programme of expansion, the quality of observations would decrease. As regards the effect on the quality of staff, work at national centres might become less interesting and so less attractive to top graduates. Recruitment to meteorology has mainly been from the middle band of the top ten per cent. Further, there would be a considerable increase in the cost of additional observations which could lead to a reduction in facilities locally, although in the tropics there would seem to be a good effect and promise of increasing accuracy of forecasts.

There was an expression of confidence that WWW would be of benefit by increasing interest and attracting staff. Members debated the status of meteorology in various parts of the world, especially with regard to developing countries, and discussed how the status of meteorology might be affected by WWW. A great deal would depend upon personalities involved and leadership. Meteorology was a difficult subject, as leading scientists had recognized, and in the past meteorology had not had its fair share of talent. It must be assumed that there is worth-while research at all levels with problems which could be worked on by small teams. Many countries would no doubt be relieved that the big problems would be dealt with elsewhere and that small-scale problems could be tackled by their own research teams. As regards economic value, it would be the advanced countries who would gain most, but they would also pay more of the bill.

One could envisage a big difference in 20 or 30 years time, with one giant computer for Europe, one major centre and even one weather service.

The economic importance of long-range weather forecasts was discussed. In India for example, where there were problems of water control and irrigation, the medium-range forecasts could be as important as longer period forecasts.

In Canada, a major item in the next few years would be the computer control of communications and high-speed data links with the U.S.A.

In the Caribbean, WWW might provide the additional help needed following the setting up of the Meteorological Institute in Barbados; also a better system for locating hurricanes was required. Although modification of large storms was desirable for many reasons, it was important to remember that in south-east Asia for example, the rain from large storms was essential to the economy.

Attention was drawn to the enormous areas of ocean surrounding New Zealand, whose real problem was not one of maintaining networks but of obtaining information over the sea areas which were not traversed by shipping lanes. Practically every ship to New Zealand was recruited for observations and there was excellent co-operation. The U.S.A. and New Zealand had put up balloons under a joint project GHOST (Global Horizontal Sounding Technique) intended as a preliminary experiment leading to satellite interrogation of balloon-borne sensors. Several hundreds of the balloons, being a fair proportion of those launched, had flown for 6 months with successful results. New Zealand had a new headquarters under construction in Wellington and had arranged to use an Elliot 503 computer experimentally for two years. The intention was to concentrate on New Zealand and surrounding sea areas and if WWW would help to fill the gaps a very important objective would be achieved.

There was also the question of the contribution to WWW by island communities. Already in some islands the proportion of income spent on meteorology was relatively high and there was little hope of governments taking further part. Meteorological observations from some islands were of more value internationally than nationally. The Voluntary Assistance Programme would therefore have to be strong.

In closing, the Chairman of the discussion said that there was a general feeling of cautious optimism. The national implementation of WWW must come first and bi-lateral aid second; failing these, the Voluntary Assistance Programme should take effect.

On the final day the discussions were mainly centred on public services, the Director-General taking the Chair. Mr J. K. Bannon, Assistant Director (Public Services), opened on the subject of forecasting services for the general public, and Mr Brazell, Senior Meteorological Officer, London Weather Centre followed with the special topic 'Forecasting weather for oil and gas exploration in the North Sea'. At the end of the general discussion which followed, the Director-General reviewed the events of the past four days and after votes of thanks and proposals for the next Conference, closed the Conference for 1967.

551.524.36:551.584.31(428)

A NOTE ON MINIMUM SCREEN TEMPERATURES IN THE HOUGHALL FROST HOLLOW

By K. SMITH
University of Durham

Introduction.—Katabatic drainage and the establishment of a nocturnal temperature inversion forms one of the most important features of valley climates, and the resulting temperatures have attracted considerable interest since Hawke[1] drew attention to the remarkably low minima recorded in the Rickmansworth frost hollow. This site has the most severe night climate yet investigated in lowland Britain, but similar effects have since been noted for numerous other climatological stations including that at Houghall in County Durham.

As shown in Figure 1, the original station at Houghall (H_1) was established at 160 feet above MSL within the Wear valley and 1 mile south-east of the Durham University Observatory, which is well-exposed on a ridge at 336 feet above MSL. Manley [2, 3] was the first to describe the unusual thermal characteristics at Houghall, showing that screen minima were occasionally 10 degF lower than those for the Observatory 176 feet above. A more detailed comparison between the two stations was made by Catchpole.[4] Using records from 1925 to 1945 he found that, although minima were consistently lower at Houghall, the differences were 'surprisingly small'. Thus, for the mean monthly screen minima, statistically significant differences were found only during autumn and early winter (September to January inclusive), whilst the mean annual difference between the two stations was 0·8 degF.

From January 1960 onwards, however, the observations at Houghall have been taken at a new site (H_2) approximately ½ mile to the north-east of the original station (see Figure 1). This present location is down on the flood-plain of the Wear and at 123 feet above MSL it is 37 feet lower than the previous site. Thus the new station is at the lowest point in this part of the valley, and, in view of the striking variations shown by King[5] to exist within short distances within the Rickmansworth frost hollow, it was decided to compare the minimum screen values for these stations in relation to the Observatory

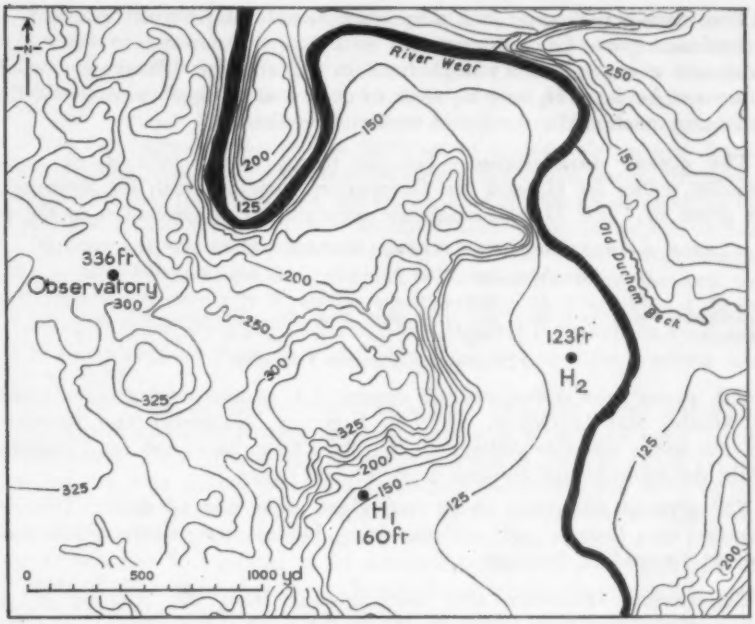

FIGURE I—LOCATION OF THE CLIMATOLOGICAL STATIONS

record. A comparison between the three stations is possible for the 15-month period from September 1959 to November 1960 when observations were maintained at both Houghall sites, whilst the values for H_2 have been compared with Observatory data for the five years 1962 to 1966.

The 15-month data period.—The mean monthly minimum temperatures show that a predictable thermal stratification exists, and that temperatures are substantially lower at H_2 than at H_1 (Table I). Only in March and October 1960 is the Observatory colder than H_1, and in all months H_2

TABLE I—MONTHLY MEAN SCREEN MINIMUM TEMPERATURES 1959–60

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
H_1	41·8	43·2	37·3	35·3	31·2	30·4	37·1	37·8
H_2	37·3	38·0	32·8	31·3	28·8	29·3	35·0	36·6
Observatory	46·4	45·4	37·7	36·0	32·7	31·7	36·8	38·7
	May	June	July	Aug.	Sept.	Oct.	Nov.	Means
H_1	42·1	47·5	48·7	47·5	46·2	45·4	35·4	40·5
H_2	41·3	46·5	47·4	47·0	44·5	43·9	33·4	38·2
Observatory	43·2	49·3	50·0	49·1	47·4	44·7	36·7	41·7

Temperatures in degrees Fahrenheit

has the lowest minima. In the four months from September to December 1959, H_2 has values on average 4·5 degF lower than the original site, and in October 1959 the difference is 5·2 degF. For the period as a whole the mean difference between the two valley sites is almost double that between H_1 and the Observatory, with an overall mean difference between ridge and valley (H_2) more than four times the value previously determined.[4]

This data-period produced some exceptional temperature gradients on individual nights. On two occasions in 1960 (19 June and 17 September) there was a contrast of 17 degF between H_2 and the Observatory, whilst differences between H_1 and H_2 were 11 degF and 14 degF respectively, thus indicating much colder conditions on the valley floor.

The 5-year data period.—For the recent period 1962–66 the mean monthly values for H_2 and the Observatory, together with the differences, are given in Table II. Although the contrasts are smaller than in the 15-

TABLE II—MEAN MONTHLY SCREEN MINIMUM TEMPERATURES 1962–66

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
H_2	28·4	31·1	31·6	37·2	41·5	47·0	47·6	47·8	46·0	41·2	35·3	30·0	38·7
Observatory	30·6	31·7	32·7	38·1	42·6	48·0	48·9	48·8	46·8	42·5	35·3	31·1	39·8
Difference	2·2	0·6	1·1	0·9	1·1	1·0	1·3	1·0	0·8	1·3	0·0	1·1	1·1

Temperatures in degrees Fahrenheit

month period, the differences are appreciably greater than those discussed by Manley and Catchpole. Only in February, November and December are the mean monthly differences less than those tabulated by Catchpole, whilst the mean annual contrast is 38 per cent larger.

The greatest difference on an individual night was 15 degF. This was recorded on 2 January 1962 and also on 13 January 1963 when a snow cover assisted the cold-air drainage

Conclusion.—Evidence now accumulating from the re-siting of the Houghall climatological station shows how the original site, which was located on the valley flank rather than the flat valley bottom, led to an under-estimation of minimum temperatures in the frost hollow. Greater absolute extremes are likely to be recorded as the data-period extends, whilst the differences between H_1 and H_2 emphasize the highly local topographic factors which influence valley climates.

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4. CATCHPOLE, A. J. W.; The Houghall frost hollow. *Met. Mag., London*, **92**, 1963, p. 121.
5. KING, M. B.; A comparison of the daily extremes of temperature at two stations in a Chiltern dry valley. *Q. Jnl R. met. Soc., London*, **78**, 1952, p. 102.

551.513:551.553.21:551.557(54)

CHANGES IN 200 MB CIRCULATION PATTERNS RELATED TO THE DEVELOPMENT OF THE INDIAN SOUTH-WEST MONSOON

By P. B. WRIGHT, B.Sc.

Summary.—The upper tropospheric circulation pattern over India from April to June is discussed, and it is shown that sudden changes occur. The advance of the south-west monsoon up the west coast of India is shown to be closely related to these changes, and also to the strength of the lower tropospheric westerly flow over the Indian Ocean.

A mechanism is suggested to explain the observed changes in the upper flow, and how they influence the progress of the south-west monsoon.

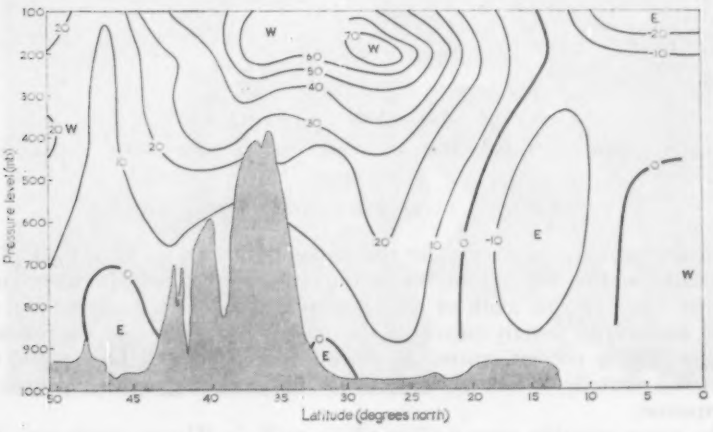
Introduction.—The onset of the monsoon in India during May and June each year is one of the most spectacular seasonal changes of weather anywhere in the world. It is an event on which the whole livelihood of the farming

community depends. Because of this dependence, it can be a disaster if the monsoon arrives too late in any area. Hence, any relationship that may be found between the date of onset of the monsoon and changes in circulation patterns during the previous weeks, would be of great economic value.

Several attempts have been made over the years to discover associations between the dates of onset of the monsoon at various places, and features of the weather of previous months in different parts of the world. Sir Gilbert Walker, who was the main early worker in this field, found correlations with phenomena as diverse as the snow accumulation on the Himalayas in May, and the pressure in South America during April and May.[1] More recently, Ramdas *et alii*[2] related the date of onset of the monsoon along the west coast of India, as determined by daily rainfall totals, to a variety of factors, including: rainfall at the Seychelles in April, pressure at Darwin in April, mean zonal component at Agra in early May, and the pressure gradient along 75°E in April.

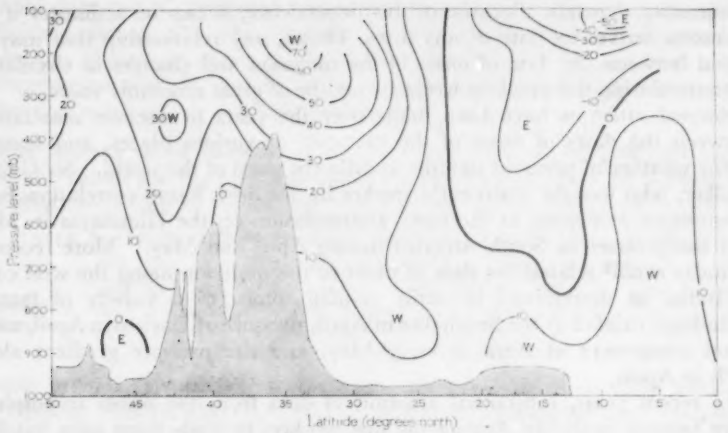
In recent years, substantial amounts of data from the upper troposphere have become available. Among the first workers to study these were Sutcliffe and Bannon;[3] they discovered substantial changes in the circulation patterns over western Asia during May and June, and found that the dates of these were linked with the date of establishment of the monsoon in India. Lockwood[4] studied these changes in more detail, describing the sequence of events at 200 mb and how it is related to the advance of the monsoon. Yeh, Dao and Li[5] showed that these changes in flow patterns could be recognized over a large part of the northern hemisphere. All these papers emphasized that the transition from spring to summer patterns is usually sudden, well defined and nearly simultaneous over a large part of the globe.

The normal circulation patterns over India.—The main features of the circulation patterns in the Indian area during the transition season from spring to summer can be illustrated by typical cross-sections along 75°E (Figures 1(*a*), (*b*) and (*c*)). Consider for example Figure 1(*a*), which

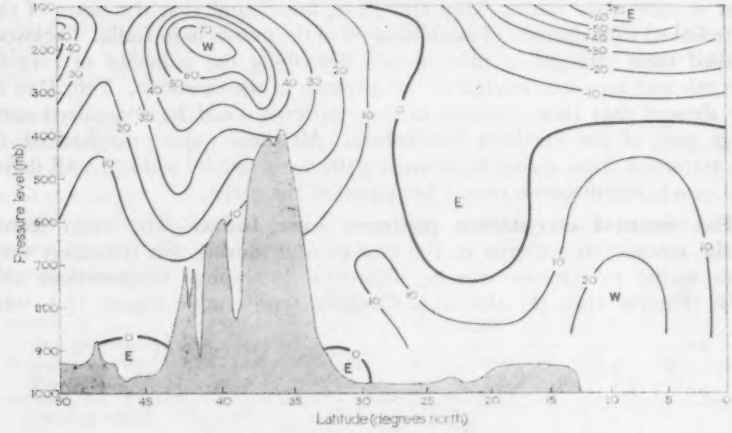


(*a*) 11–20 May 1959

FIGURE 1—CROSS SECTION OF MEAN ZONAL WIND COMPONENT ALONG 75°E
Speed in knots. Components from the west are positive.



(*b*) 21–30 May 1959



(*c*) 31 May to 9 June 1959

FIGURE I—CROSS SECTION OF MEAN ZONAL WIND COMPONENT ALONG 75°E (*continued*)

Speed in knots. Components from the west are positive.

represents the mean conditions for the 10-day period 11–20 May 1959. This shows a broad westerly current, the subtropical westerly, centred near 200 mb, with its main jet axis south of the Himalayas at about latitude 30°N; the upper easterly, an easterly current in the upper troposphere near the equator; another easterly current centred at 700 mb over peninsular India; and the equatorial westerly, a westerly current in the lower troposphere centred at the equator.

The mean monthly cross-sections along 75°E in 'Upper winds over the world'[6] indicate that, between April and July, the axis of the subtropical westerly moves from 25°N to 45°N, crossing the Himalayas, while the ridge

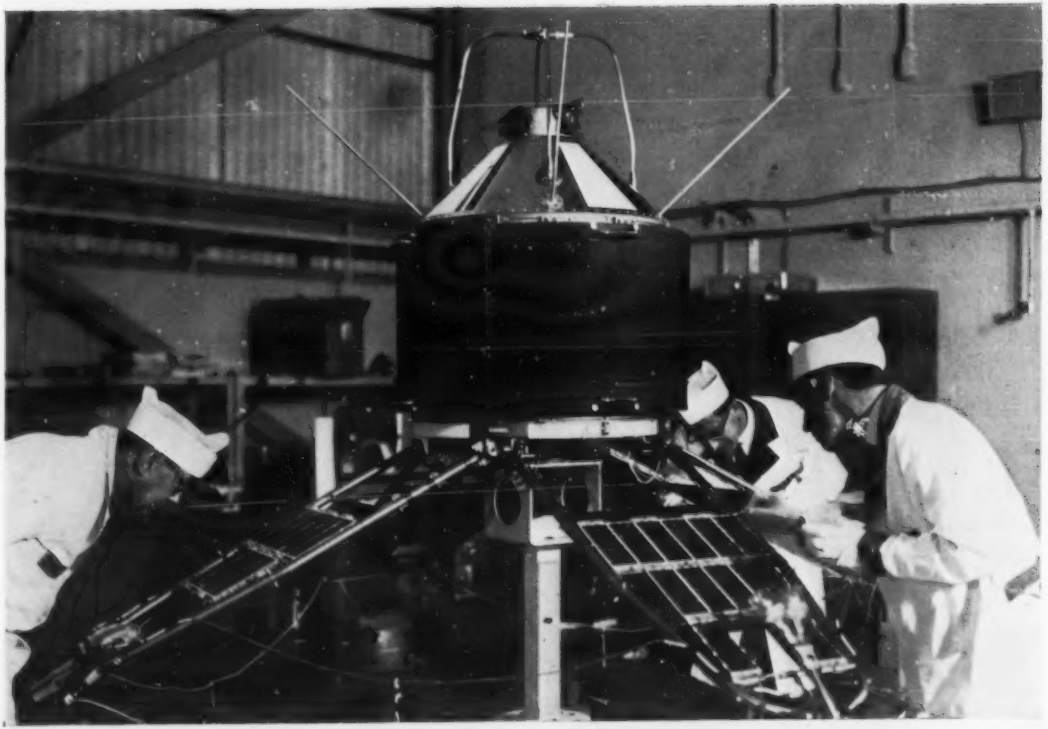


PLATE I—FINAL CLEANING AND INSPECTION OF ARIEL 3

The Meteorological Office experiment equipment can be seen mounted on top of the satellite. (See page 295.)

To face page 304

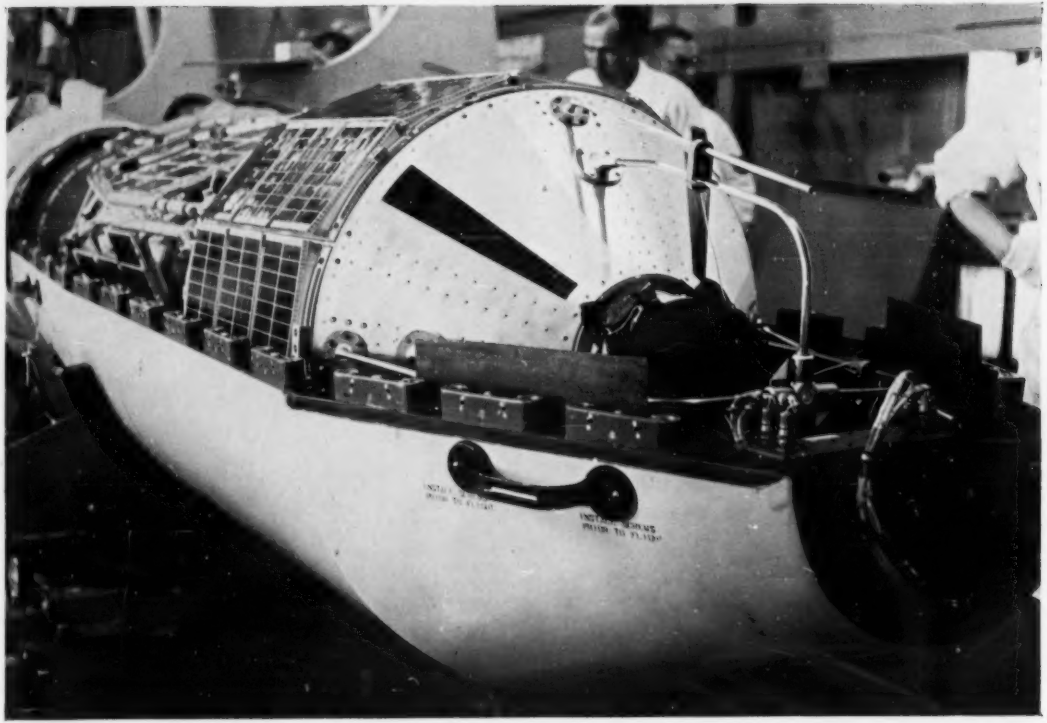


PLATE II—ARIEL 3 MOUNTED ON THE FOURTH STAGE OF A SCOUT ROCKET WITH ONE HALF OF THE NOSE CONE FITTED

(See page 295)

PLATE III—ARIEL 3 AND THE SCOUT ROCKET IN THE LAUNCHER

(See page 295)

PLATE IV—DELEGATES AT THE EIGHTH CONFERENCE OF COMMONWEALTH METEOROLOGISTS IN MAY 1967

Standing, left to right : Mr R. H. Clements (United Kingdom), Mr L. A. D. I. Ekanayake (Ceylon), Cdr R. K. Alcock and Mr J. S. Sawyer (United Kingdom), Mr E. G. Davy (Mauritius), Mr P. M. A. Bourke (Ireland, attending as an observer), Mr C. M. Taylor (East Africa), Mr R. Frost (Zambia), Mr G. J. Bell (Hong Kong), Mr K. V. W. Nicholls (the Caribbean), Mr V. R. Coles (United Kingdom), Dr G. O. P. Obasi (Nigeria), Mr G. M. D. Rudder (Barbados), Mr P. J. Meade (United Kingdom), Mr R. J. F. Andersson (Botswana). *Sitting, left to right :* Dr L. S. Mathur (India), Dr J. F. Gabites (New Zealand), Mr N. A. Akingbehin (Nigeria), Dr B. J. Mason (United Kingdom), Mr W. J. Gibbs (Australia), Mr J. R. H. Noble (Canada), Mr K. Rajendram (Singapore). (See page 296.)

To face page 305

axis at 200 mb moves from 10°N to 30°N; the upper easterly also extends northwards and increases markedly in strength. The equatorial westerly moves northwards and strengthens to become the 'monsoon westerly', and this movement is manifested on the surface by the onset of the monsoon.

Figure 1, giving mean cross-sections for 11–20 May, 21–30 May and 31 May to 9 June 1959, shows that in that year all the three-monthly changes were substantially accomplished within 20 days; the jet axis, for example, moved from 28°N in mid-May to 40°N in early June. The other years studied (1956–58, 1960) showed similar sudden changes although the date of onset varied widely from year to year.

Upper tropospheric winds at New Delhi, Bombay and Madras.— It can therefore be seen that the advance of the monsoon up the west coast is closely related to the changes in the upper tropospheric currents. In order to study the relationship in more detail, the 12-km zonal wind components at New Delhi, Bombay and Madras have been considered for the period April to July of each of the years 1956–65. These particular stations were chosen because :

(*a*) they lie fairly close to 75°E and should therefore adequately represent the changes occurring over western India;

(*b*) they had reasonably complete radiosonde records over the period; and

(*c*) in combination, they should indicate the major changes in the positions and strengths of the subtropical westerly jet, the upper easterly current, and the 200 mb ridge axis.

The daily values of the component show frequent short-period oscillations, of about 3 to 5 days. These are sometimes of large amplitude, and are caused by the passage of synoptic-scale disturbances such as mobile waves in the westerlies. Five-day running means were used in order to suppress these oscillations and so obtain a clearer view of the longer-lasting changes, and graphs were produced for all three stations. Examples of the graphs for New Delhi and Madras, namely those for April to June 1962, are reproduced in Figure 2, while the graphs for Bombay for all 10 years are shown in Figure 3.

The graphs for New Delhi show that there were large-amplitude oscillations around a mean westerly component of about 60 kt during the spring season (April–May), followed by a steep drop in wind speed over a short period at the end of May or beginning of June. This was followed by a more gradual change to an easterly component of about 10 kt in July. Oscillations occurred also during the summer, but they had a smaller amplitude than those of spring.

The change from spring to summer values was rather more evenly spread over the period at Bombay than at New Delhi, and the short-period oscillations were of smaller amplitude. However, rapid decreases of zonal component did occur, but it is interesting to note that these were not often coincident with similar decreases at New Delhi.

Short-period oscillations were much less noticeable at Madras than at the other two stations, especially during April and May. The value of the component was usually near zero during April and May, although in some years there was a westerly component of about 20 kt in April, and in 1956 the zonal component had become 20 kt easterly by 28 April. In June and July, there was an easterly component of about 30 to 40 kt.

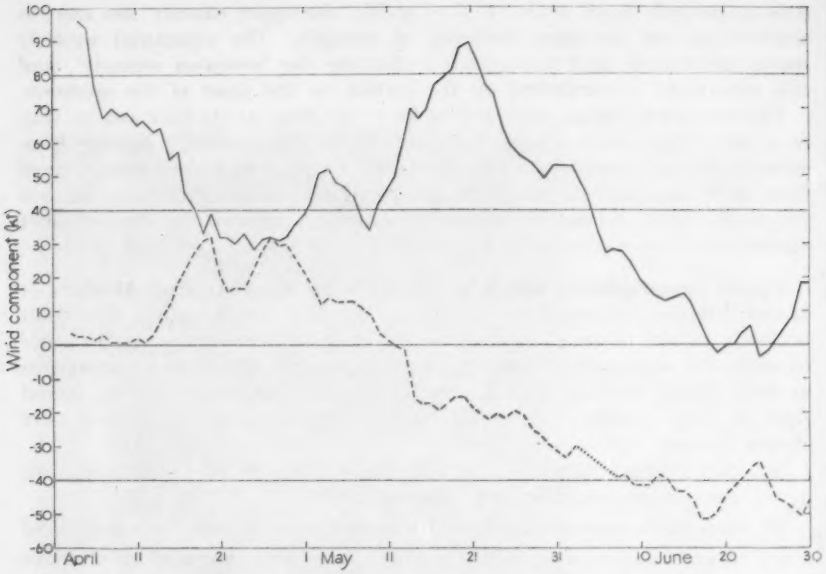
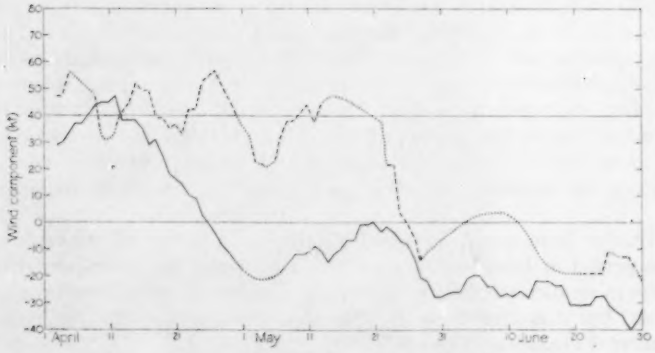


FIGURE 2—GRAPHS OF FIVE-DAY RUNNING MEANS OF THE 12 KM ZONAL WIND COMPONENT AT NEW DELHI AND MADRAS, 3 APRIL TO 30 JUNE 1962

Values for five-day running means are written against the central day. Dotted lines indicate interpolation using less than three days' data. Components from the west are positive.

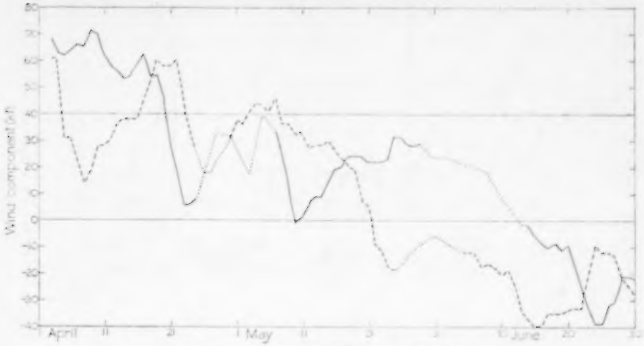
——— New Dehli - - - Madras



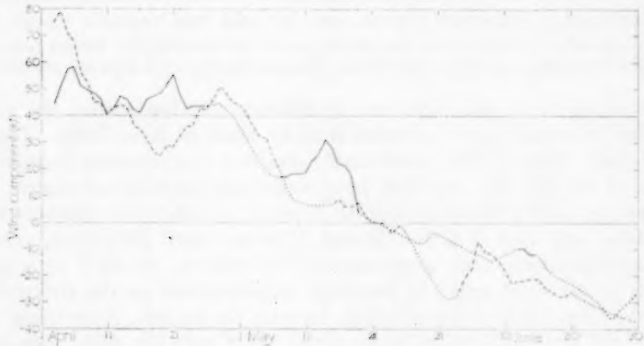
(*a*) ——— 1956, - - - 1957

FIGURE 3—GRAPHS OF FIVE-DAY RUNNING MEANS OF THE 12 KM ZONAL WIND COMPONENT AT BOMBAY BETWEEN 3 APRIL AND 30 JUNE FOR VARIOUS YEARS

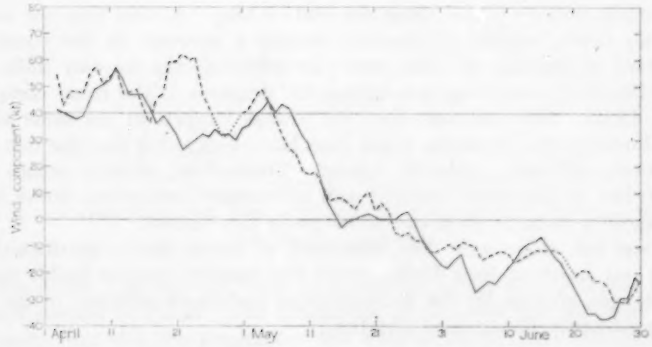
Values for five-day running means are written against the central day. Dotted lines indicate interpolation using less than three days' data. Components from the west are positive.



(*b*) ——— 1958, - - - 1959



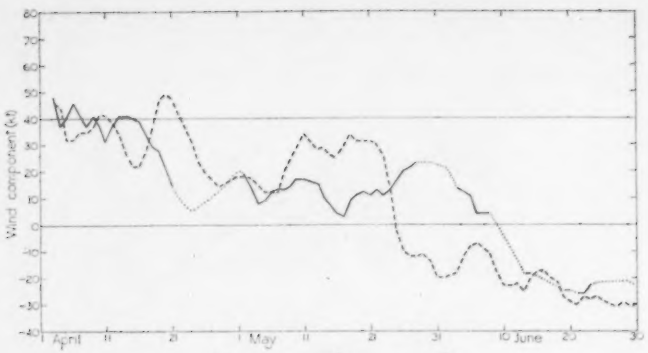
(*c*) ——— 1960, - - - 1961



(*d*) ——— 1962, - - - 1963

FIGURE 3—GRAPHS OF FIVE-DAY RUNNING MEANS OF THE 12 KM ZONAL WIND COMPONENT AT BOMBAY BETWEEN 3 APRIL AND 30 JUNE FOR VARIOUS YEARS (*contd*)

Values for five-day running means are written against the central day. Dotted lines indicate interpolation using less than three days' data. Components from the west are positive.



(*e*) ——— 1964, - - - 1965

FIGURE 3—GRAPHS OF FIVE-DAY RUNNING MEANS OF THE 12 KM ZONAL WIND COMPONENT AT BOMBAY BETWEEN 3 APRIL AND 30 JUNE FOR VARIOUS YEARS (*contd*)

Values for five-day running means are written against the central day. Dotted lines indicate interpolation using less than three days' data. Components from the west are positive.

These changes can be explained as follows. During spring the westerly jet, gradually weakening, is situated near or south of New Delhi. The wind speed at New Delhi is thus particularly sensitive to variations in position or intensity of the jet axis, so that large-amplitude oscillations occur. These variations also affect Bombay, but to a lesser extent, while Madras is close to the ridge axis and is little affected. During April and May, combined northward movement and weakening of the westerly jet lead to a gradual reduction in the wind speed at Bombay, superimposed on the shorter-period variations; New Delhi is less affected, because the jet axis, if anything, moves closer, so the general level of wind speed there remains high. Meanwhile, the 200 mb ridge axis moves gradually northward to just north of Madras, resulting in a small easterly component there.

The main changes occur about the end of May. At this time the 200 mb ridge axis moves rapidly northward, causing a decrease in the zonal wind component at Bombay to near zero. In addition, the jet axis shifts north of the Himalayas, resulting in a substantial decrease in the zonal component at New Delhi. This decrease does not always happen at the same time as that at Bombay, but is usually a few days later, suggesting that the two events are distinct, although probably related. Meanwhile, Madras comes under the influence of the upper easterly, and its easterly component shows oscillations around a value of 30 kt due to surges in this current.

The 200 mb ridge axis then continues to move slowly northward to a position just north of New Delhi, while the easterly current builds up, and these changes account for the more gradual variations observed in the zonal wind components during June and July.

The advance of the monsoon.—In the *Indian Daily Weather Report*[7] charts are reproduced showing the northern limit of the monsoon (NLM) each day over India. From these charts, graphs have been produced (Figure 4) showing for the years 1956–65 the latitude of this limit in the sector between the west coast and 75°E (or, to the north of the Gulf of Cambay, the sector 72°–75°E).

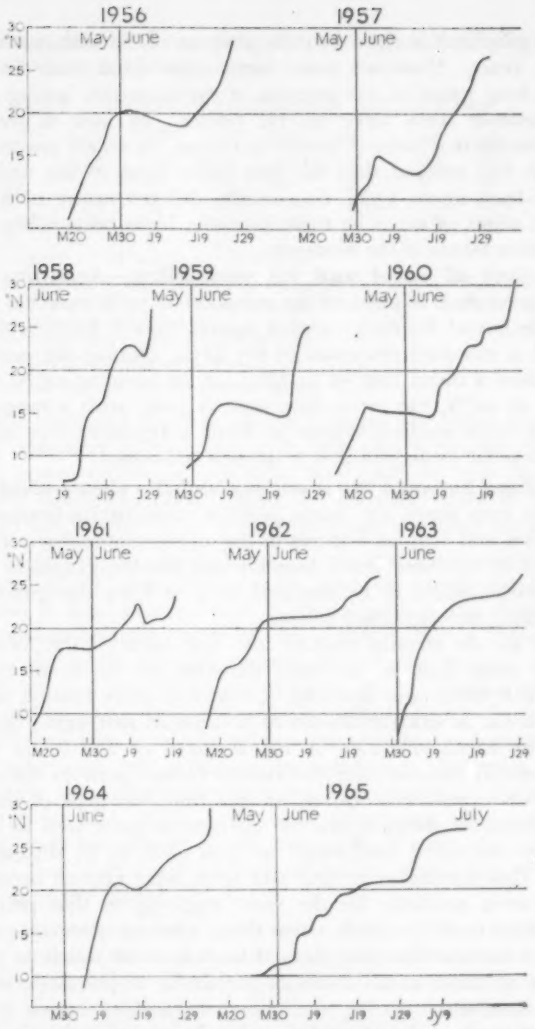


FIGURE 4—GRAPHS SHOWING THE ADVANCE OF THE MONSOON ALONG 75°E FOR THE YEARS 1956–65

In the years 1956–59 the term Intertropical Convergence Zone (ITCZ) was used instead of NLM. The graphs for those years showed more erratic movements than did the graphs for the later years, possibly because ITCZ was defined differently from NLM. Also, ITCZ retreated several degrees southwards during weakenings of the monsoon, or sometimes faded out *in situ* and later reappeared some 10 degrees farther south (as in 1956). To obtain consistency in the graphs, those for 1956–59 were corrected by assuming that NLM, unlike ITCZ, remained nearly constant in position during pauses in the advance of the monsoon.

From the graphs, it is clear that the progress of the monsoon varied greatly in different years. However, some similarities stand out. In many years there was a long pause in the progress of the monsoon, lasting about a fortnight; sometimes there were several pauses. In fact, it seems that the monsoon proceeds in a series of 'bursts' or surges. As an aid towards simplifying the study, it was noticed that the first main burst of the monsoon always extended at least up to 13°N, but usually did not reach 22°N, so for convenience the dates of onset at these latitudes have been taken as the dates of the two main bursts of the monsoon.

Normal date of onset and its variability.—According to Ramdas *et alii*,[2] the mean date of onset of the monsoon at 13°N over the period 1891–1950, as determined by daily rainfall figures, was 3 June, with a range of 29 days and a standard deviation of 6·3 days. During the period 1956–65, our results show a mean date of 31 May for the onset at 13°N, with a range of 26 days; at 22°N, the mean date was 20 June, with a range of 22 days. Thus the 10 years studied appear to form a representative sample of the past 70 years as far as distribution of dates is concerned.

Relationships between the monsoon and the upper wind changes.—Investigations were made into many possible relationships between the bursts of the monsoon and various features of the upper tropospheric flow patterns, as represented by the New Delhi, Bombay and Madras graphs of mean winds. The relationships found to be the best, and to have the greatest potential forecasting value, are described below.

Relationship I.—As already noticed, the first burst of the monsoon occurs at about the same time as the main decreases in the zonal component at 200 mb at New Delhi and Bombay. Looked at more closely, however, this relationship is not as straightforward as it seems at first sight; another factor appears to be involved. This is the strength of the lower tropospheric equatorial westerly current over the Indian Ocean prior to the development of the monsoon circulation. Since, at this time, the axis of this current is near the equator, its strength can be represented quite well by the value of the mean 700 mb zonal component at Gan (1°S, 73°E) during the period 1–10 May. This particular period and level were chosen because 700 mb mean charts were available for the years 1956–59, so that estimates of the zonal component could be made when there were no observations from Gan. Nevertheless, a study of the data showed both that the winds at 700 mb were representative of those at all levels of the lower troposphere, and that the mean zonal component during the period 1–10 May varied from year to year in the same way as the mean during April, suggesting that it is representative of some persistent feature of the circulation.

It was found that the stronger the equatorial westerly the shorter the delay between the decrease of zonal wind component at 200 mb at Bombay and the establishment of the monsoon at 13°N; a difference of 2 kt in the value of the 700 mb component at Gan was equivalent to about one day's delay in the progress of the monsoon. Relationship I can therefore be stated as follows :

The first main burst of the monsoon occurs within about a fortnight of the date on which the 200 mb westerly wind component at Bombay falls permanently below 5 kt, the burst being earlier in years when the equatorial westerly is strong.

Table I shows details of the dates for each year, and the delays after allowing for the strength of the westerly.

TABLE I—DETAILS ILLUSTRATING RELATIONSHIP I

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
B	25A	25M	12J	22M	19M	20M	15M	18M	6J	25M
V_θ	(2)	(4)	(12)	(2)	16	21	6	–6	22	18
B'	24A	23M	6J	21M	11M	9M	12M	21M	26M	16M
D_{13}	24M	4J	14J	4J	20M	21M	19M	4J	7J	5J
D_{13}–B'	30	12	8	14	9	12	7	14	12	20

A = April M = May J = June

Notes : B = date when 200 mb westerly component at Bombay fell below 5 kt
V_θ = value of 700 mb westerly component at Gan, 1–10 May, in knots
B' = adjusted date (B–$\frac{1}{3}V_\theta$)
D_{13} = date when monsoon reached 13°N
D_{13}–B' = delay from adjusted date
Values in brackets are estimated from charts.

We see from this table that, in all but 2 years, the delay was between 7 and 14 days. However in 1956 and 1965, there were notably longer delays. In 1965, the reason for the longer delay was probably that the first burst, which occurred about 30 May (Figure 4), extended only to about 11°N, while the burst which affected 13°N on 5 June was in reality the second burst.

The year 1956 was an unusual one. From the mean streamline charts for 10-day periods for each of the years 1956–60 (produced in connexion with this work) it was observed that in many parts of the tropics and subtropics the seasonal changes occurred very much earlier in 1956 than in the other 4 years. In particular, the greater part of the seasonal movement of the 200 mb ridge axis over India had already occurred before the beginning of May, instead of being delayed until late May or early June as in other years. This observation is confirmed by the graphs for Bombay, in which the unusual behaviour during May 1956 stands out. The 700 mb patterns in 1956 similarly show late-season features; in particular, the pattern over India during 1–10 May looks much more monsoonal than pre-monsoonal. The rainfall figures for stations on the west coast of India show that in 1956, but in none of the other years studied, substantial quantities of rain fell on about 1 May in many places.

Thus it is suggested that the monsoon in fact occurred at the beginning of May 1956, although it was not mentioned in the *Indian Daily Weather Report* that year before 14 May. The delay in the monsoon following the fall in wind speed at Bombay would then be in agreement with that in the other years.

Relationship II.—The second main burst of the monsoon occurs about a month after the start of the main decrease in the 200 mb westerly wind component at New Delhi, the burst being earlier in years when the equatorial westerly is strong. Table II shows the details for each year.

In this case, the delays are all in the range 28 to 35 days, with three exceptions.

In 1958 and 1963 the delay was about 10 days less than expected on the basis of the other years. However, it will be seen that in both years the surges which first affected 22°N did not proceed much farther north, and were followed by later surges. The later surge in 1958 affected 22°N on 28 June,

TABLE II—DETAILS ILLUSTRATING RELATIONSHIP II

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
N	19M	24M	8J	29M	25M	21M	22M	19M	24M	8J
V_0	(2)	(4)	(12)	(2)	16	21	6	−6	22	18
N'	18M	22M	2J	28M	16M	10M	19M	22M	13M	30M
D_{22}	22J	26J	22J	25J	14J	10J	17J	12J	23J	2Jy
$D_{22}-N'$	35	35	20	28	29	31	29	21	41	33

M = May J = June Jy = July

Notes : N = date when main decrease of 200 mb westerly component at New Delhi began
V_0 = value of 700 mb westerly component at Gan, 1–10 May, in knots
N' = adjusted date ($N-\frac{1}{2}V_0$)
D_{22} = date when monsoon reached 22°N
$D_{22}-N'$ = delay from adjusted date
Values in brackets are estimated from charts.

and that in 1963 would have reached 22°N (if the earlier surge had not already got there) about 22 June. If these later surges are considered to be the relevant ones, the delays were 26 and 31 days respectively, much closer to the values for the other years.

In 1964 the delay was about 10 days longer than expected.

Relationship III.—The first burst of the monsoon occurs about 40 days after the start of the major decrease in April of the 200 mb zonal wind component at Bombay.

Relationship IV.—The second burst of the monsoon occurs about 65 days after the start of the major decrease in April of the 200 mb zonal wind component at Bombay.

These two relationships are particularly interesting because of the long time interval between 'cause' and 'effect'.

There is a significant change in the upper tropospheric wind field during April; the date of this occurrence appears to be closely related to the dates of *both* the first burst *and* the second burst of the monsoon. This change, whatever it may be, is identifiable by a major decrease in the zonal wind component at 200 mb at Bombay. The date of the start of the first main decrease in the zonal component which occurs on or after 6 April has been taken for this purpose. While for some years it was difficult to decide which decrease should be taken, it will be seen from Figure 3 that, with the exception of 1960, the decrease chosen was always the most marked of those which began between 6 April and 30 April.

TABLE III—DETAILS ILLUSTRATING RELATIONSHIPS III AND IV

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
B_1	13A	28A	18A	23A	7A	6A	13A	25A	17A	22A
D_{13}	24M	4J	14J	4J	20M	21M	19M	4J	7J	5J
$D_{13}-B_1$	41	37	57	42	43	45	36	40	51	44
D_{22}	22J	26J	22J	25J	14J	10J	17J	12J	23J	2Jy
$D_{22}-B_1$	70	59	65	63	68	65	65	48	67	71

A = April M = May J = June Jy = July

Notes : B_1 = date of start of decrease in 200 mb zonal component at Bombay
D_{13} = date when monsoon reached 13°N
$D_{13}-B_1$ = delay for first burst
D_{22} = date when monsoon reached 22°N
$D_{22}-B_1$ = delay for second burst

In the case of the first burst the delays ranged from 36 to 45 days, with two exceptions, namely 1958 and 1964, when the monsoon reached 13°N much later than expected. The second burst showed delays between 63 and 71 days, with 1963 and 1957 as exceptions.

The years 1958 and 1964 have several distinctive features in common. At the end of May, namely about the time when the first burst of the monsoon was expected, the zonal component at Bombay was much greater in both these years than in the other years ; and it has already been shown in the first relationship how this feature affects the first burst of the monsoon. Figure 4 also shows that in these two years there was no long pause in the monsoon's progress, at any rate south of 22°N, so that the first burst was followed by the second with less than the usual delay. This is confirmed by the fact that the delays of the second burst in these years were not exceptional.

It therefore seems that there was some factor, which operated during 1958 and 1964, which is identifiable by the unusual wind graphs at Bombay during those years, and which delayed the first burst of the monsoon but not later bursts.

In 1963 the monsoon reached 22°N earlier than expected. This was because, as was decided in the case of the second relationship, the first burst extended farther north than usual. In 1957, the delay of the second burst was again less than expected, but no simple explanation can be offered; however, it is worth pointing out that the delay of the first burst was also less than average. In 1965, the delay of both bursts was rather greater than usual; this may have been because, as previously suggested, it was the second burst which affected 13°N, and therefore the third which affected 22°N, while these relationships are really concerned with the first and second bursts.

The causes of the monsoon.—It is worth considering now the likely causes of the monsoon, in order to see if any explanation of these rather remarkable relationships is possible from physical considerations.

The prime reason for the existence of the marked seasonal weather changes of the 'monsoon lands' of Asia is well known, namely that the effect of the annual north–south migration of the pressure belts of the world is accentuated in this sector by the particular land–sea distribution. However, in order to explain the process of advance of the monsoon in greater detail, it is necessary to study more closely the physical characteristics of the area.

During the winter the Asian continent north of 40°N becomes intensely cold, and the presence of the Tibetan Plateau extends this cold area even farther south. As the sun moves north the continent is at first slow to warm up, owing to the extensive snow cover; meanwhile north India, being protected from the north by the Himalayas and in a clear anticyclonic régime, warms up, if anything, rather faster than would be expected for its latitude. All this contributes to keeping the main zone of strong thermal contrast, and therefore the subtropical westerly jet, in a southern position.

About early April, the snow line begins to recede rapidly and, with the sun already north of the equator, the Asian continent starts warming quickly and the thermal contrast weakens. This results in a weakening of the jet, demonstrated by the observed decrease in the zonal wind component at Bombay.

The land–sea distribution between 50° and 100°E is such that, in midsummer, the zone of most intense heating is probably around 25°–30°N (Sutcliffe and Bannon[3]). This causes the pressure belts to move farther

north during summer than they would do if the sector were either all sea (as in the Pacific, where little northward movement occurs) or all land (in which case the additional heating of the zone 0°–20°N would cause the belts to occupy a more southerly position). Indeed, it is quite likely that this land–sea distribution, with the boundary approximately along the tropic, is almost an ideal one for producing the maximum northward extent of the belts in summer. Thus at some time between April and July a large northward movement has to take place.

The reason why most of this change should be concentrated within two or three weeks is less clear; but the cause may well lie outside the Indian sector, namely in the positions of the main troughs and ridges in the circumpolar westerlies. For example, if a trough in the upper troposphere were situated over the western part of the Tibetan Plateau, one would expect that the flow of air round this trough would be steered by the mountains into a latitude farther south than it would be if the area were flat. It would then need only a small longitudinal movement of this trough to take it away from the influence of the mountains, and therefore cause the jet to jump to a more northerly position. It is reasonable to suppose that some small displacement of this sort is responsible for the observed sudden northward movement of the jet in May or June. Since the positions of troughs and ridges in this sector are controlled as much by the general strength of the westerly circulation and the positions of upstream troughs as by local thermal conditions, it is possible that the sudden movement is due to a general rearrangement of the trough positions round the hemisphere. Further work is in progress in studying the relationships between the positions of the troughs in the westerlies and the changes occurring over India, and it is hoped that this will substantiate these suggestions.

Influence of the upper tropospheric flow on the monsoon.—The mechanism by which the upper tropospheric flow influences the monsoon probably involves the low-pressure area which deepens over north India between March and July. The sudden movement of the jet may in some way induce a fall of pressure over India; at any rate, a sharp drop in the zonal wind component at Bombay is usually followed closely by a marked fall of pressure over north India. The resulting increased north–south pressure gradient over peninsular India then causes a steady increase in, and northward movement of, the equatorial westerly current, culminating in a surge of the monsoon. The stronger the westerly is at the beginning of the process, the sooner the surge occurs.

This hypothesis suggests the possibility that each surge of the monsoon current is the result of a preceding sudden change in the flow pattern at 200 mb.

Conclusions.—There is a close connexion between the circulation patterns of the upper and lower troposphere in the India area. Rapid large-scale changes take place in the 200 mb circulation pattern each year during May or June. The dates of onset of the monsoon along the west coast of India are closely related to the major changes at 200 mb, and four relationships have been presented which demonstrate this. These relationships have obvious forecasting value.

Important factors in causing the upper tropospheric changes to be so sudden and in determining their date of occurrence may be :

(i) the land–sea distribution in the Asian sector;

(ii) the Asiatic highlands, both by providing a low-latitude snow cover during winter and by their steering of the air flow; and

(iii) the positions of troughs and ridges in the circumpolar westerlies.

The link between the monsoon surges and the changes in the upper flow may reside in the effect of the movement of the jet on the deepening of the low-pressure centre over India.

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REVIEWS

Radiation climate of the Arctic, by M. K. Gavrilova. $9\frac{3}{4}$ in $\times$ 7 in, pp. iv + 178, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1-5 Portpool Lane, London EC1, 1966. Price: £4 1*s*.

In this slim volume M. K. Gavrilova has tackled the very difficult task of assessing our present knowledge of the Arctic radiation régime. Not only have data from many different sources been assimilated, but an attempt has been made to extend these data by computation to give a more complete picture. This latter aspect of the book is open to criticism but serves as a good indicator of current Russian thought on the matter; however, the book's most valuable contribution to the subject is as a source of references to data. There are some 290 of these of which 180 provide a most comprehensive catalogue of Russian work in this field.

The radiation units used are consistent throughout and are based on the calorie, but it is a pity that the results are given on the European (unreduced) radiation scale and not the International Pyrheliometric Scale (IPS) (1956). Particularly so since the bulk of the large quantity of tabular data are computed values and consequently could easily have been converted to the IPS scale.

The most serious criticism of this book is its lack of both an index and a list of figures and tables. This seems to be a common fault with Russian publications. The annotation at the front of the work indicates that it is intended for use by researchers and specialists in this field but, whilst the material presented is valuable, as a reference book it is almost useless without

an index. Few scientists these days can afford to spend time wading through a complete detailed text to find what they require.

With this book, the Israel Program for Scientific Translations have continued their high standard of translation, although there are occasional lapses into laboured English, — like the use of the word 'episodically'. The diagrams, however, are not, on the whole, very clear. Though this may be due to poor quality in the original Russian version, the maps given in figures 21 to 62 would have been far more legible and usable had they been presented at least twice their present size, even at the expense of limiting the tabular data in Appendix V.

This is certainly a valuable collection of references and data and it may possibly become a standard work, but it is marred by insufficient attention to the requirements for use.

C. H. DEAN

Weather and climate, by R. C. Sutcliffe. 9 in × 6 in, pp. 206, *illus.*, Weidenfeld and Nicolson, 5 Winsley Street, Oxford Circus, London W1, 1966. Price : 36*s*.

This book is intended for the general reader who is not a scientist. The subject is therefore treated without mathematics, although there are many numerical figures and graphs, and some excellent diagrams. It is possible that by omitting so much mathematics the author has made the book more difficult for the scientist from another field who would find some of the discussion much easier to follow with an equation or two. Such a reader would also be interested in a somewhat more technical bibliography in addition to the one given.

In presenting his subject to the layman, the author seems to be somewhat apologetic: it is surely not necessary nowadays to defend so fully the importance of his subject. But this is doubtless the natural reaction to the many criticisms and complaints to which the meteorologist is peculiarly prone.

After beginning with these criticisms, I must say how much I enjoyed reading the book: Professor Sutcliffe is to be congratulated on translating so much specialist science so well into non-technical terms. The book reached me while I was preparing a course in meteorology for M.Sc. students, and I found it an invaluable source of background material for one part of the course.

The book begins with a general description of the atmosphere and of measuring techniques currently used. With this as a basis, the author goes on to discuss the small-scale phenomena, such as cloud formation and rain, which are the immediate causes of local weather. He then proceeds to large-scale systems, such as anticyclones and depressions, which are so often the generators of the smaller systems. And so he builds up to a discussion of the general circulation of the atmosphere and its interrelation with the systems already described. In the course of all this, there is an account of how the ideas can be included in a forecasting system. This is one place where the book is already out of date, for it states that in the United Kingdom numerical forecasting is 'still essentially supplementary to the judgement of the responsible

forecasters', and, to some extent at least, this situation has changed in the short time since the book was published.

In the nature of things it is impossible to discuss climate without a considerable knowledge of weather and its causes. This is one reason why only a small part of the book is concerned with the second half of the title. A second reason is doubtless that the study of climate is less advanced than that of weather and it is hardly profitable to list, let alone to discuss, the 'nine and sixty ways of constructing a theory of climatic change' referred to. Nevertheless, in this brief account, Professor Sutcliffe gives a clear picture of the situation and its problems.

The question of man's control of the weather is discussed in some detail, and the enormous difficulties (and expense) involved in any useful attempt to do this are pointed out. Professor Sutcliffe is not hopeful that this will prove to be a profitable proposition in the foreseeable future, but he finishes his excellent book with some of his own speculations about the future of the science.

RUTH H. ROGERS

Particles in the atmosphere and space, by R. D. Cadle. 9½ in × 6½ in, pp. viii + 226, *illus.*, Reinhold Publishing Corp., New York, 1966. Agent: Chapman and Hall Ltd., 11 New Fetter Lane, London, EC4. Price: 80*s*.

The jacket blurb remarks: 'One of the only books available dealing with fine particles in our universe, this work brings together in one volume information which has been scattered through a voluminous literature covering such subjects as astronomy, air pollution, cloud physics, meteorology, radioactive fall-out, and "space sciences".' Whatever one may make of the first phrase the remainder of the sentence properly describes this book. Inevitably much has necessarily had to be condensed and simplified but plentiful references to original sources are provided.

There are three chapters of direct interest to the meteorologist, concerned respectively with particles in the troposphere, particles in the stratosphere and mesosphere, and radioactive fall-out. In these chapters the author describes the many ways in which particles are produced: evaporation of salt water, wind erosion, volcanic eruptions, fires and industrial processes, meteors, nuclear explosions etc., and indicates in each case the sorts of particles produced. There is a section called 'Cloud physics', dealing with the formation of cloud particles and rain and hail, but this is curiously unbalanced: of the 18 pages in the section, 4 are concerned with the rather elaborate equations expressing, precisely, the very small supersaturation required for cloud droplets to form; 2 carry a discussion on techniques for measuring cloud particle sizes; and 12 pages are devoted to the artificial production of rain!

The chapter on radioactive particles is almost the longest in the book and deals mostly with fall-out patterns and predictions. The chapter on stratospheric and mesospheric dust is almost the shortest and is disappointing. The mesosphere is the link between the atmosphere and 'space'. We are told, in a succeeding chapter, how much dust there is in 'space'. It would have been interesting to see a summary of people's views on what sort of dust concentrations we might expect in the mesosphere. There is nothing about this.

Other chapters deal with 'Interplanetary dust', 'The moon' and 'Planets, comets and galactic dust'. It is surprising to note that in the section on 'Evidence of dust on the lunar surface' evidence from satellite photographs is dismissed in a short paragraph beginning 'One additional bit of evidence should be mentioned, namely, the photographs obtained by RANGERS VII, VIII and IX'.

The book is well produced, is almost free from misprints and carries a good index.

R. FRITH

LETTERS TO THE EDITOR

551.589.1(4):519.2

The summers of north-west Europe

The additional data presented by Mr N. E. Davis,[1] especially those relating to wind direction and the frequency of blocking patterns, provide impressive support for the hypothesis of a biennial variation in the summer weather over north-west Europe.

The further suggestion that this is related to the near-biennial oscillation in the equatorial stratospheric winds and to a biennial variation, that Labitzke[2] pointed out, in the behaviour of the 'sudden warmings' of the temperate stratosphere does little to strengthen the case.

The variation in the equatorial stratospheric winds has been shown to have a 26-month period, so that every 13 years a phase change may be expected. Moreover, Scherhag[3] disagrees with Labitzke's interpretation and expresses the view that the stratospheric warming spread westwards in 1958 and 1963 and eastwards in 1959, 1961 and 1964. This indicates a phase change about 1963 and he further claims that the March circulation at 10 mb shows a near 2-year variation but again with a phase change about 1963. In March 1958, 1960, 1962 and 1963 there was a vortex centred over the pole while in March 1959, 1961 and 1964 it was displaced to north-east Asia with a high cell over north-west Canada.

It is interesting to note that Baur,[4] 40 years ago, drew attention to a 2·2-year variation in temperature at Berlin and Zwanenberg, air pressure at Stikkisholm (Iceland), rainfall in the upper Rhine plain and the water level in the Rhine at Mannheim.

If there is an association between the tropospheric circulation over north-west Europe in summer and events in the stratosphere, then one must suppose it is stronger at one phase of the stratospheric cycle than at another. It would be worthwhile examining the summer data to see if the pre-eminence of the odd summers arises from a marked effect over a period of years, every 26 years, with a random variation around the out of phase period.

Headquarters, Royal Air Force, Germany. M. K. MILES

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Reply by Mr N. E. Davis :

With reference to the letter of Mr M. K. Miles, I have examined the sequences of good and bad summers at Kew and Stonyhurst. If we consider mean daily maximum temperature and, as in the article, mark years + or − according to whether they were warmer or cooler than the previous summer, then sequences of + − + − or longer when the + were odd years occurred as follows :

Kew	Stonyhurst
1887 – 1891	1885 – 1895
1898 – 1902	1897 – 1903
1920 – 1926	1920 – 1926
1933 – 1938	
1946 – 1950	1943 – 1950
1954 – 1962	1953 – 1960

These sequences occurred at intervals of about 11 years with 1 missing at Kew and 2 missing at Stonyhurst.

Out of phase sequences when the + years were even years occurred only for 1903–10 and 1963–66 at Kew and 1906–10 at Stonyhurst. There is no 26-year period but the phase change at Kew does coincide with the change in the stratospheric warming type as expressed by Scherhag.

Some 26 years of stratospheric observations are required before definite conclusions can be made regarding stratospheric cycles.

CORRIGENDA

Meteorological Magazine, July 1967, p. 195, the figure caption: for 'The unit is 0·1 mm' read 'The unit is 0·01 mm'; p. 200, the vertical axis of Figure 3 should be marked '*R*' not '*r*' ; Letter to the Editor, p. 222, add:

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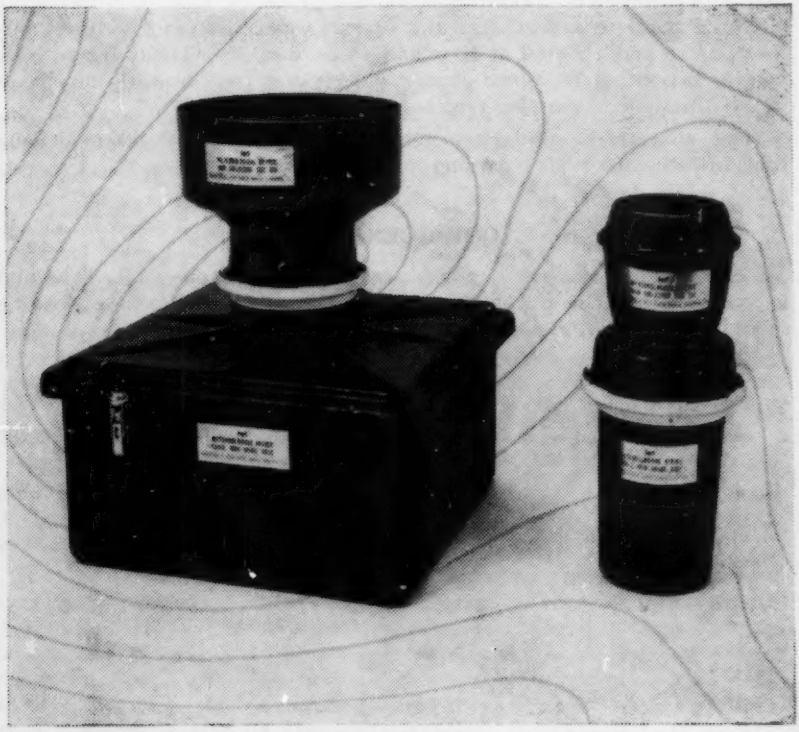

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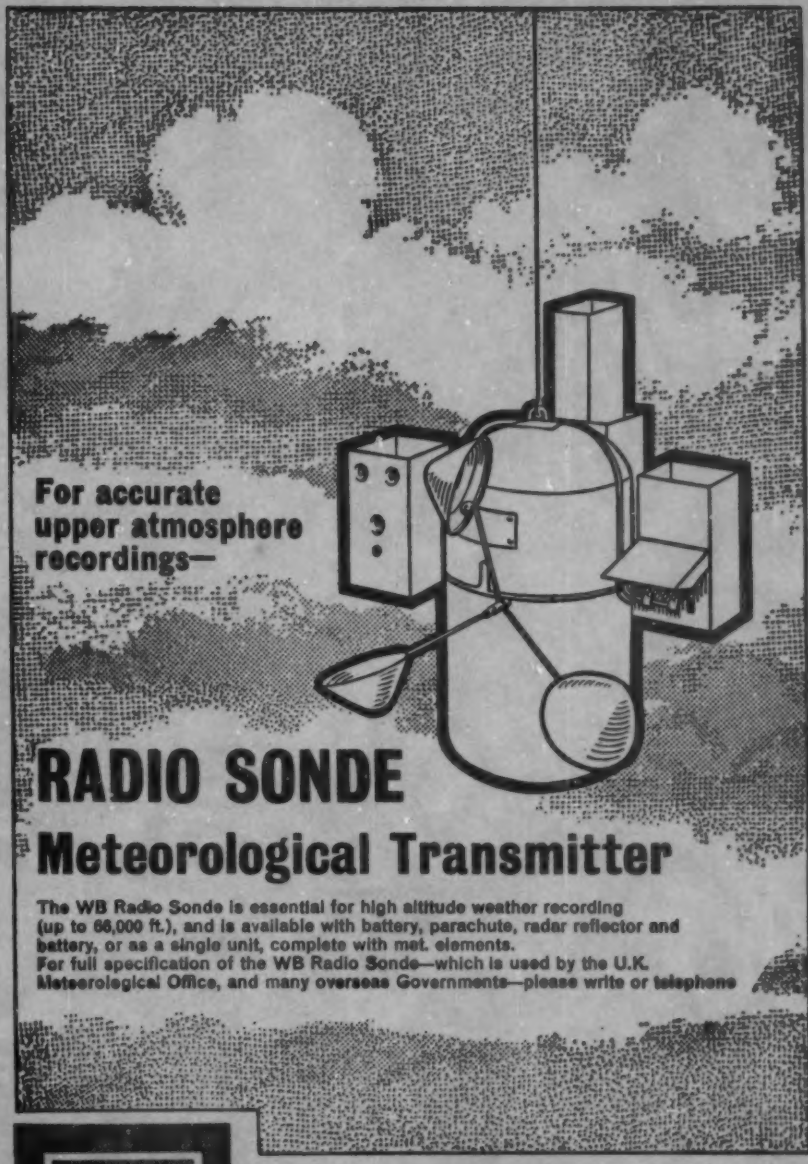

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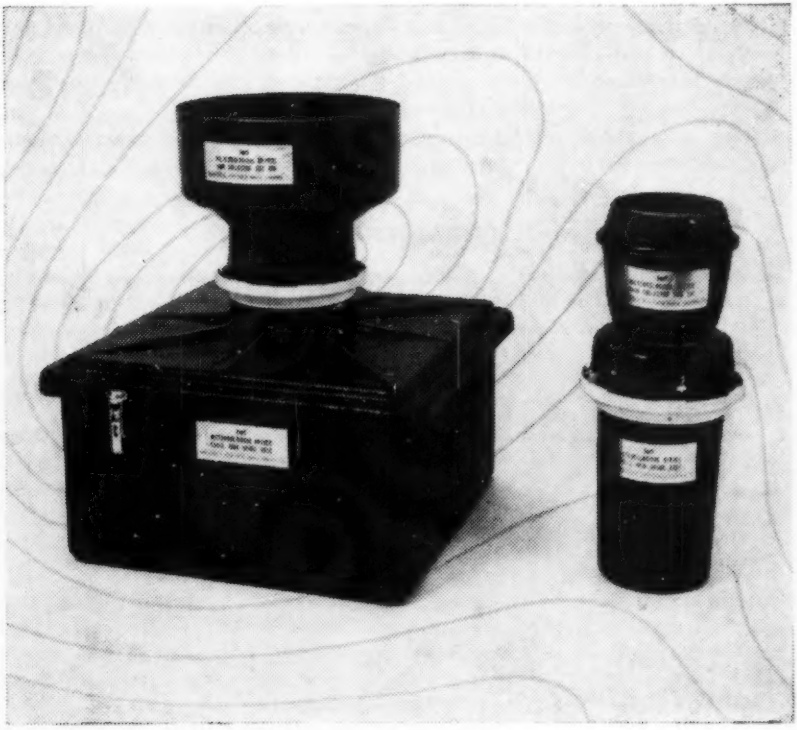

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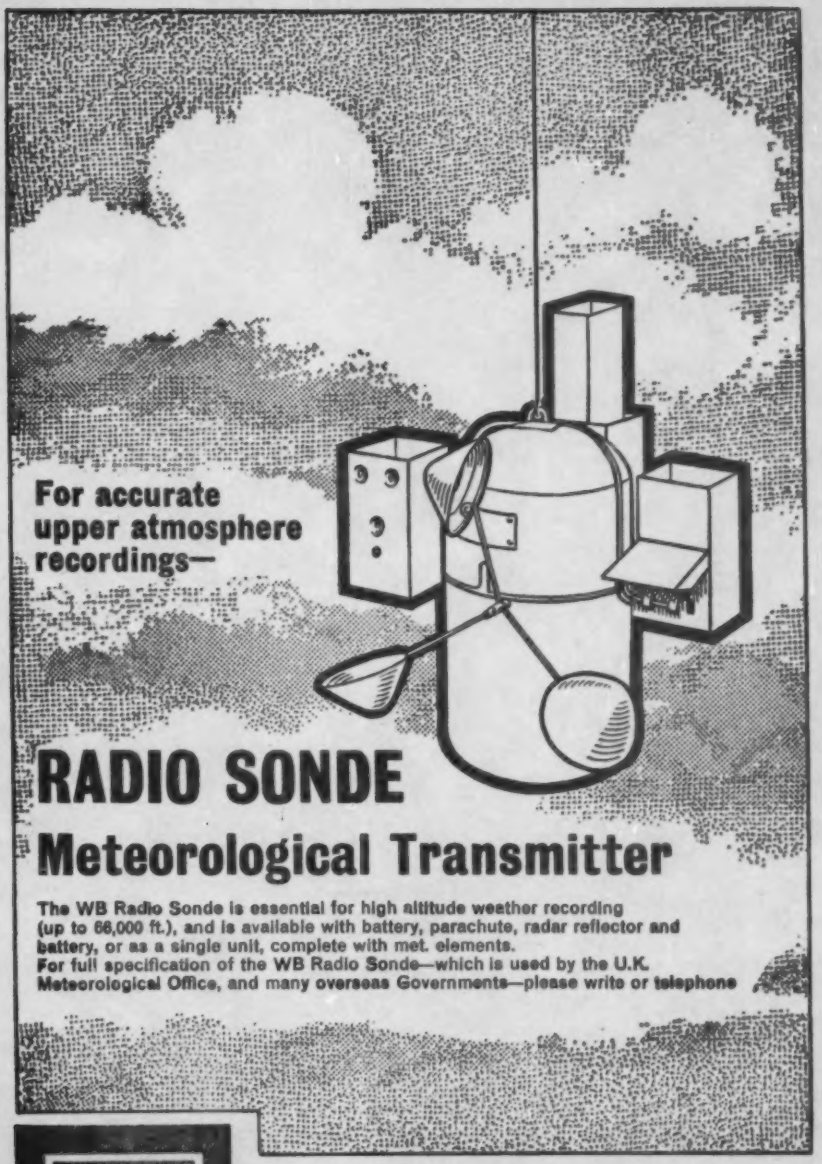

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